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Oil sector and CO₂ emissions in Saudi Arabia: asymmetry analysis

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ABSTRACT Saudi Arabia is an oil-abundant country, and gather a significant portion of its income from the oil sector. Owing to the country's over-dependency on the oil sector, increasing greenhouse gas emissions due to economic growth have often been neglected. The present research aims to estimate the effects of non-oil income per capita, the oil sector income share, urbanisation, and gasoline price on the CO₂ emissions per capita in Saudi Arabia throughout 1970–2014. We use the latest nonlinear cointegration technique to estimate the asymmetrical effects of the oil sector on CO₂ emissions. We found a long-run relationship in our hypothesised model. We also found a positive impact of non-oil income and urbanisation on CO₂ emissions per capita and a negative effect of gasoline price. Moreover, a positive asymmetrical impact of oil income share on CO₂ emissions is observed. The increasing oil income share has a more significant positive impact on CO₂ emissions than that of decreasing oil income share. Moreover, the effect of increasing oil income share is found greater than non-oil income, urbanisation, and gasoline price. It is suggested to use tight environmental policies while formulating economic growth and urbanisation policies. Further, the economy should cut down its dependency on the oil sector to ensure a cleaner environment.

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Introduction

The oil sector does not only contribute to the income of the oil-exporting country. It may have significant environmental consequences as well. The upstream oil segment is involved in the exploration and production of oil. It eventually leads to the mid-stream engagement in transmission and downstream sectors involved in the delivery to the end-user. On a global level, there are over 40,000 oil fields; the numbers of people living or working close to these oil fields are 6 million (O'Callaghan-Gordo et al., 2016). While the methods and technologies used for oil exploration and production are advanced enough, there are certainly some loopholes that impact the overall environment of the neighbouring areas and, in some instances, the entire location as well (Johnston et al., 2019).

The types of pollution resulting from oil production are various, including water, soil, and air, and these effects are usually long-lasting. Another debate that arises from this idea is the fact that oil production increases income, which can improve the overall infrastructure of the country. Hence, there are many reasons to believe that oil production is responsible for greenhouse gases (GHGs) emissions. CO₂ emissions count for a substantial proportion of GHGs and are responsible for increasing global warming (EPA, 2019). These activities are releasing GHGs emissions and could have adverse health effects as well, if carried near the residential localities.

The Middle Eastern region is one of the world's most enriched areas in terms of oil reserves, especially since the oil discovery in Saudi Arabia back in the 1930s (Nasir et al., 2019). Oil is a major income source in the Middle Eastern region, which is why the fact that these activities are affecting public health gets ignored. Johnston et al. (2019) analysed the impact of the upstream oil segment on the environment and public health, and proved that oil drilling and extraction activities do raise environmental concerns on a large scale. Since the 1980s, the potential oil production of the Middle Eastern region has doubled, which has improved the income of the area. From 11 million barrels per day, the figure rose to 15 million in the 1990s, and by the first decade of the twenty-first century, this number has gone up to 18 million. In the last decade only, this industry in the GCC region has seen a growth rate of 24% (IOGP, 2019), where Saudi Arabia stands as the most significant contributor. Out of all the contract awards in the region in Q4 2018 and Q1 2019, oil and gas contracts accounted for around 27% of the total pie, which is worth \$835 billion (Sertin, 2019).

Saudi Arabia is committed to contribute to the Paris Agreement in making the world an environmentally friendly place. Saudi power and water sectors have adopted many policies, including installing up to 50 gigawatts of renewable and nuclear energy, which can reduce carbon intensity in the kingdom generated during power production. Further, the introduction of fuel price reforms in the country can help in increasing the domestic oil price, which may assist in reducing the local oil consumption and pollutant emissions (KAPSARC, 2019). The increase in domestic oil price plays a significant role in shaping the welfare of the oil-exporting Saudi Arabian economy through decreasing domestic oil consumption and increasing the oil exports (Gonand et al., 2019). Moreover, oil prices could affect the stock markets of oil-exporting countries (Siddiqui et al., 2019), which may put an impact on the overall economic activities in these countries. In the Vision 2030, the Kingdom targets low air, sound, water, and soil pollution in the domains of strategic objectives of national industrial development and national transformation programme, designed to offer a fulfilling the healthy life (Government of Saudi Arabia, 2019).

Because of its significance in the Middle Eastern, oil has an impactful role in urbanisation as well. In Saudi Arabia,

specifically, the oil industry strongly influences urban planning because of the large number of people this industry employs. For example, the Saudi petrochemical company (SADAF) is surrounded by eight districts, each have 30,000–38,000 of the population in Jubail (Al-But'he and Saleh, 2002), which has been sharply expanding in the recent years due to job availability in the industry. Saudi Arabia went through a rapid phase of urbanisation through the '70 and '80s, and most of it had to do with the oil industry in the country. For example, the urban population was just 48.67% of the total population in 1970, and it has been shifted to 76% in 1989 (Saudi Arabian Monetary Agency, 2019).

Although there is some literature available on how the oil sector affects the environmental profile of a country (Johnston et al., 2019; Roberts et al., 2019; Bekun et al., 2019), it is missing in the case of Saudi Arabia. The analysis is crucial because the increasing role of the oil sector in the economy may result in environmental degradation. Therefore, this present study attempts to find the role of the oil sector in the environmental profile of Saudi Arabia, considering asymmetry in the relationship and effects of energy policy and urbanisation are tested on the CO₂ emissions. Saudi Arabia has targeted the economic diversification from oil production in the Vision 2030. The estimated parameters of our study might help design the diversification policy while caring for the environmental effects.

Literature review

In Saudi Arabia, economic growth took off a few decades ago after oil discovery, and the environmental effect of oil production has been ignored. That leaves a void in the literature and needs to research the ecological effects of the oil sector. Hasanov et al. (2018) mentioned in their paper that oil and its consumption have a positive impact on CO₂ emissions in the oil-exporting countries. It is suggested that the trade of oil and its consumption have a robust environmental impact in the region, and this effect is spread across the short and long-term as well. These ecological effects primarily show up as a higher rate of CO₂ emissions in the country and sustain for a more extended period. Trade openness is also expected to put an influence on CO₂ emissions of the country, and this is true if trade liberalisation occurs through the oil segment.

Moreover, it is primary to understand how urbanisation can impact CO₂ emissions. Using Stochastic Impact by Regression on the Population, Affluence, and Technology (STIRPAT) model, Chen et al. (2019) conducted a study using data from 188 prefecture-level cities of China. They found the Environmental Kuznets Curve (EKC) with an inverted U-shaped relationship between urbanisation and CO₂ emissions. Further, they found that a 1% increase in population, 1% increase in affluence, and a 1% increase in industry share in Gross Domestic Product (GDP) could increase the CO₂ emissions by 0.96%, 1%, and 0.17%, respectively. Moreover, they mentioned that a country moved up the urbanisation scale; there might be a high rate of CO₂ emissions. Owing to urbanisation, a state may focus more on infrastructural development and may pollute the environment. The country moves towards further economic growth and urbanisation. The clean environment is also becoming a priority in the second stage by adopting environmentally friendly strategies. Hashmi and Alam (2019) extended the STIRPAT by adding energy policy variables. They tested the dynamic relationship between selected variables, including CO₂ emissions, population, economic growth, and environmental regulations in selected OECD countries. The panel investigation provided more profound insights into the connection between the variables. They found that environmentally friendly patents reduced the CO₂

emissions in the region, and increasing tax revenue per capita also helped to reduce emissions as well.

Wang et al. (2019) investigated the relationship between urbanisation and CO₂ emissions in China. They indicated that the effect of urbanisation on the CO₂ emissions decreases in agriculture, forestry, animal husbandry, fishery, and water conservatory sectors, and increases in the construction sector. Further, they found the positive effect of energy intensity on the CO₂ emissions with the coefficient ranging from lowest 0.2813 for industry sector and highest 0.8363 for transportation, storage, and postal industry. Fan et al. (2019) mentioned something similar about urbanisation and economic growth and their impact on the environmental and social changes in the economies going through significant transitions. The relationship between urbanisation and the environment is multi-dimensional. While a country promotes social conditions, economic development and urbanisation lead to environmentally degrading consequences.

Ali et al. (2019) analysed how urbanisation has an impact on CO₂ emissions in Pakistan. With the analysis, a long-term relationship was proven in their research, and a short-run causality was also found from urbanisation to the CO₂ emissions. Other than that, it was argued that no matter if economic growth and urbanisation sustained for a short or long-term period, it did result in environmental degradation, which came in the form of CO₂ emissions in Pakistan. The strength of the correlation can be judged by the fact that 1% increase in urbanisation and 1% increase in income led to up to 0.84 and 0.28% rise in CO₂ emissions, respectively. Other than that, short-term causality also suggests that urbanisation leads to environmental degradation, and urbanisation strategies can lead to environmental changes to a large extent. It is up to the countries to promote environment-friendly urbanisation so that the pollution does not get out of hand while the country is focusing on growth so much.

Han et al. (2018) found that the urban population was responsible for higher pollution concentration while the rural population helped in decreasing pollution concentration. Liang and Yang (2019) mentioned that urbanisation and economic growth lead to pollution in the form of regional wastewater discharge at the first stage of development, and pollution is reduced at the second stage of development. They found the inverted U-shaped relationship between economic growth and pollution with 2.883 and -0.1637 coefficients of economic growth and its square. This inverted U-shaped relationship is also found between urbanisation and pollution with 0.0598 and -0.0004 coefficients. With higher economic growth and urbanisation, pollution becomes inevitable, and that is when the country has to make a smart decision about whether it wants to give more push to growth and urbanisation or makes the entire process sustainable so that nothing goes wrong on the environmental side as well. Charfeddine et al. (2018) found the bidirectional causality between urbanisation and electricity consumption and unidirectional causality from electricity consumption to economic growth. Further, they found that urbanisation had an inelastic effect on electricity consumption, and 1% increase in urbanisation might increase by 0.58% of electricity consumption. They argued that if focusing on the environment too much and trying to improve its quality impeded economic growth. The results of the study suggest that with a lot of focus on improving the quality of the environment, energy consumption reduces, which eventually affects the economic growth of the country.

Mikayilov et al. (2018a) utilised a period of 1992–2013 and five different cointegration methods to identify the relationship between CO₂ emissions and economic growth in Azerbaijan. Through all the methods, a positive and linear relationship was seen between economic growth and CO₂ emissions, which suggested that the EKC hypothesis did not hold in Azerbaijan. Any

imbalances caused by elasticity can be adjusted in a short amount of time. Mikayilov et al. (2018b) conducted a study on 12 Western European countries by decoupling of GDP and CO₂ emissions. They found a positive relationship between CO₂ emissions and economic growth. Further, income elasticity of emissions is found lesser than one for eight countries and greater than one for the rest of four countries. Therefore, CO₂ emissions grow more than proportionate change in income in the case of four countries and lesser than proportionate change in the case of eight countries. The time-varying income elasticity has been estimated from a minimum value of 0.22 for Germany to a maximum value of 2.52 for Switzerland. In the case of oil-exporting countries, Hasanov et al. (2016) investigated and found that oil price, population age group, and income are significant determinants of energy use. Further, the age range 35–64 could contribute more to energy use compared to other investigated age groups. Assuming cubic relationship, Hasanov et al. (2019) investigated the EKC hypothesis in Kazakhstan using data of a period 1992–2013 and applying five cointegration tests. They did not find the EKC and found the U-shaped relationship in the income and CO₂ emissions with a unit income elasticity approximately.

Using 1990–2010 data from 33 countries, Menegaki and Tsagarakis (2015) investigated nonlinear relationships between income and energy production of oil, gas, and coal in three different models. They proved the existence of EKC with the inverted U-shaped relationships between income and energy production with the inflection points at GDP per capita of 7331, 6204, and 5970 in the oil, gas, and coal models, respectively. They mentioned that with more economic growth, countries start to consume more energy, and the environment does get ignored to some extent. One major reason is that while the economy is taking off, the aspect of how the natural resources are being exhausted at an exponential rate gets neglected. A considerable part of that economic growth and urbanisation is fuelled by fossil fuel production. In a recent study, how non-renewable energy use can put an asymmetrical impact on economic growth and CO₂ emissions is tested by Awodumi and Adewuyi (2020). They found that oil consumption, along with gas, led to economic growth but also led to higher CO₂ emissions in most the investigated African countries. The existence of asymmetric effects of oil and gas consumption was also seen in CO₂ emissions and economic growth. The results suggested that oil-producing countries must look towards diversifying their production and consumption portfolio to mitigate the negative effects. Mahmood et al. (2019b) investigated and corroborated the EKC in Tunisia and also found the asymmetrical impacts of trade openness on the CO₂ emissions. In a panel investigation of 22 African countries, Mensah et al. (2019) found the bidirectional causality among fossil fuel energy use, economic growth, and CO₂ emissions. Further, they found the unidirectional causality from oil price to the CO₂ emissions.

Farhani et al. (2014) investigated the EKC in the Middle East and North Africa (MENA) region, including Saudi Arabia. They found the validity of EKC in the panel estimates. In the country-specific analysis, they found a monotonic positive effect of income on the CO₂ emissions in Saudi Arabia and positive (adverse) effects of energy consumption (trade) as well. Omri et al. (2015) re-investigated the EKC in the MENA region. They found the EKC hypothesis in the panel estimates and also found the positive effects of energy consumption and trade on the CO₂ emissions. In the country-specific results, they found evidence of EKC in Saudi Arabia. Further, they also found the positive effects of urbanisation and energy consumption on CO₂ emissions in Saudi Arabia.

In the oil production and pollution relationship, Roberts et al. (2019) found in the simulation analysis that future global oil production is expected to increase the global average temperature

through increasing GtCO₂ emissions. Further, increasing heterogeneity in the oil-deposits and carbon tax is expected to reduce the oil-related emissions. According to Bekun et al. (2019), renewable energy can improve the environmental profile of a country. The natural resources rent can be strongly associated with economic growth, and long-run natural resources rent dependence has affected the environment of the country. However, it was also found that higher economic growth and fossil fuels led to higher CO₂ emissions. Attala et al. (2018) argued that Saudi Arabia kept domestic energy prices lower than the international market, which gave a big push to the energy demand in the Kingdom.

In the case of Saudi Arabia, literature is silent to find the effect of the oil sector on pollution emissions but has focused on the other determinants. For example, Raggad (2018) investigated the determinants of pollutant emissions. He found the positive effects of income and energy use on the CO₂ emissions, but a minute negative impact of urbanisation was seen. The elasticity parameters were found 0.416, 0.562, and -0.024 for income, energy use, and urbanisation, respectively. Alsaedi and Tularam (2020) tested the association between electricity consumption, GDP, and peak load in Saudi Arabia. With the help of a Vector Autoregression (VAR) analysis on data from 1990–2015, positive growth rates in the selected variables are shown in the forecasted results. Additionally, Granger causality indicates that peak load, electricity consumption, and GDP seem to have a bidirectional relationship.

Samargandi (2017) investigated the EKC hypothesis in Saudi Arabia but found a linear relationship between income and CO₂ emissions. Further, they found the positive effects of industrial and service sectors on the CO₂ emissions, but they found statistically insignificant results of the agriculture sector and technology innovation. Considering asymmetry in the model, Mahmood et al. (2018) investigated the relationship between economic growth and CO₂ emissions in Saudi Arabia. Also, they tested the effects of financial market development (FMD) on CO₂ emissions. They again came with the same finding that EKC was found valid, but Saudi Arabia was found at the first stage of EKC. Further, they found the asymmetrical effects of FMD on CO₂ emissions. In the same line, Mahmood et al. (2019a) tested the asymmetrical effects of agriculture sector on the CO₂ emissions in Saudi Arabia and re-investigated the EKC as well. They found Saudi Arabia in the first phase of EKC, and the asymmetrical effects of increasing and decreasing agriculture sector on the CO₂ emissions are also reported.

Raggad (2018) and Omri et al. (2015) investigated and found mixed evidence of the negative and positive effect of urbanisation on the CO₂ emissions in Saudi Arabia, respectively. Both studies used the energy consumption in the CO₂ emissions model and have attempted biases in the model specification. Jaforullah and King (2017) claimed that CO₂ emissions data is derived from energy consumption, and using it in the pollution model may change the magnitude and/or sign of the coefficients of other determinants. Caring this issue, this paper analyses the effects of economic growth, urbanisation, the income share of the oil sector, and domestic oil consumption on the CO₂ emissions per capita in Saudi Arabia using the period 1970–2014. Further, the increasing and decreasing trends of any independent variable do not necessarily have the same direction and/or magnitude of effect on the dependent variable as an increasing trend of a macro-economic variable may shift into a decreasing trend suddenly and sharply (Keynes, 1936). We care about this issue in the relationship between the oil sector's income share and CO₂ emissions per capita, which is a significant focus of this present study. Table 1 shows the literature summary of oil-exporting countries.

As seen in the literature, several studies talk about how the oil sector is related to the environmental condition of the country

and what is the role of economic growth in the rise of ecological degradation. Some studies talk about urbanisation, leading to higher pollution issues. With all the present literature, there is not enough research that connects the dots and provides a clear view of how the oil sector can affect the environment negatively or positively in the oil-producing country like Saudi Arabia. Additionally, the association among CO₂ emissions, oil sector, and urbanisation should be explored more deeply as well to comprehend the possibility of asymmetry in the relationship. Since a significant part of the Saudi economy heavily depends on its oil sector activities and urbanisation is also continuously growing side by side. Therefore, there is a need to explore where these two segments are leading the country in terms of the environment.

Theoretical framework and methods

Saudi Arabia heavily depends on oil production, as 33.42% of GDP is generated from the oil sector (Saudi Arabian Monetary Agency, 2019). The revenue generated by the oil sector is continually being injected into the economic mechanism. Therefore, oil has a substantial role in the economic activities and environment of the country. Being a self-sufficient country in oil, Saudi Arabia uses that opportunity to use oil as a financial tool to get ahead in the economic battle in the Middle Eastern and the world as well. Further, infrastructure development is one primary segment that gets benefits from oil revenues. In that entire cycle of growth, income generation, and infrastructure development, the environment usually gets ignored, and that is why the oil sector and its growth eventually lead to GHGs emissions.

Economic growth and urbanisation have a strong role to play in the environment of a country. The idea of urbanisation, leading to CO₂ emissions can be justified through many reasons, but one of the most apparent connections is through energy consumption. As a country is focusing more on urbanisation and development of new and advanced infrastructure in its old and new cities, the developmental activities require energy consumption. With massive infrastructure being involved in these operations for a more extended period, not only the natural resources of the country are continuously used in the form of fuel, CO₂ emissions from their use and wastes go back into the air, soil, and water as well, which eventually negatively affect the environment.

The effect of urbanisation on the overall environment raises a question on the activities of growth and architectural activities. No matter if the effects of urbanisation and the oil sector have a long-term adverse impact on the environment, these realise the economies to improve and to make their activities more sustainable and environmentally friendly. In this context, the idea of social cost must be incorporated as well since it defines how far a country should go to improve its economic position. Looking at the oil sector growth and urbanisation from a standalone point of view, their overall benefits to the economy are presented in a specific period. However, considering the social cost of these activities, several factors need to be given importance. It is possible that the social cost and how hard these segments hit the environment on a short or long-term basis leave a never-ending impact. Hence, in real terms, the net effect of these activities starts becoming harmful to the country, which needs attention.

To capture the environmental effects, Ehrlich and Holdren (1971) analysed the impact of population growth because, as the population increase, per capita returns reduce. For consumption purposes, a lower number of trees would survive, leading to the destruction of the environment. They proposed the environmental Impact of Population, Affluence, and Technology (IPAT) model. This model has the shortcoming of assuming unit elasticity for all mentioned factors. Therefore, we are utilising the STIRPAT model proposed by Dietz and Rosa (1994) to relax the

Table 1 Literature summary of oil-exporting countries.

Authors	Region	Major findings
Fan et al. (2019)	Vietnam	Economic development influenced the urbanisation and urbanisation damaged the environment.
Roberts et al. (2019)	Global	Increasing heterogeneity in oil deposits and carbon tax helped in reducing the emissions from oil.
Charfeddine et al. (2018)	Qatar	Bidirectional causality between urbanisation and electricity consumption and unidirectional causality from electricity consumption to economic growth were found.
Mikayilov et al. (2018a)	Azerbaijan	Monotonic and inelastic effect of economic growth on the CO ₂ emissions was found.
Hasanov et al. (2016)	Oil-exporting countries	Oil price, income, and population age group were significant determinants of energy use.
Hasanov et al. (2019)	Kazakhstan	EKC was not found, and the U-shaped relationship between income and CO ₂ emissions was observed.
Raggad (2018)	Saudi Arabia	Monotonic effect of income on the CO ₂ emissions and a positive association between energy usage and CO ₂ emissions were found. The impact of urbanisation was negative on the CO ₂ emissions.
Farhani et al. (2014)	MENA including Saudi Arabia	EKC was found in the panel estimates. In the country-specific analysis, EKC was not found in Saudi Arabia, and positive (adverse) effects of energy consumption (trade) were found on the CO ₂ emissions.
Omri et al. (2015)	MENA including Saudi Arabia	EKC was found in the panel of MENA countries but not in the country-specific estimates of Saudi Arabia. Energy consumption and trade had positive effects on the CO ₂ emissions in the panel estimates. Urbanisation and energy consumption had a positive impact on CO ₂ emissions in Saudi Arabia.
Samargandi (2017)	Saudi Arabia	EKC was not found. Industrial and service sectors had positive effects on the CO ₂ emissions, but the effects of the agriculture sector and technology innovation were found insignificant statistically.
Mahmood et al. (2018)	Saudi Arabia	Inverted U-shaped relationship between income and CO ₂ emissions and asymmetrical effects of FMD on the CO ₂ emissions were found.
Alsaedi and Tularam (2020)	Saudi Arabia	The bidirectional relationship between peak load, electricity consumption, and GDP.
Mahmood et al. (2019a)	Saudi Arabia	EKC was validated, and asymmetrical effects of the agriculture sector were found on the CO ₂ emissions.

assumption of unit elasticity and to empirically capture the environmental effects of urbanisation, non-oil economic growth, and the oil sector. We are considering CO₂ emissions as an environmental variable as CO₂ emissions carry a significant proportion of GHGs emissions. Like Dietz and Rosa (1994), York et al. (2003) also used the STIRPAT framework as analytical tools to discuss the factors that drive environmental impact. The research provided a strong theoretical and practical implication about the spread of ecological effects and how the environmental footprint of a region can get defined. The concept of ecological elasticity was also developed using the STIRPAT model. In the discussion, it was mentioned that the population could turn out to be a significant driver in higher pollution emissions, which eventually negatively impacts the environment in a country. The present study utilises the urbanisation for the environmental effect of population. Since urbanisation is a sign of development and modernisation, a monotonous increase is seen in the level of emissions as a result of urbanisation.

Further, affluence represents the average consumption per person in a country, and GDP per capita is usually used as a proxy of affluence. Increasing GDP per capita can increase the consumption of energy-oriented products and can have environmental effects in turn. Lastly, technology may capture the environmental effect other than population and affluence. Shi (2003) utilised the industrial share in GDP for technology impact. Most of the industrial sector consists of the oil sector in Saudi Arabia. Therefore, we are utilising the share of the oil sector in GDP to serve the purpose. A more recent study conducted by Hashmi and Alam (2019) introduced the environmental regulation and patents as a policy variable in the STIRPAT model and termed it as STIRPART model. The data on environmentally friendly patents or taxes on energy consumption are not available in Saudi Arabia. Therefore, we utilised the gasoline price of 95-

octane. As any change in government subsidies or taxes on energy consumption is responsible for gasoline price fluctuation. Moreover, gasoline prices and electricity prices are also moving in the same direction as most of the electricity production is also from oil and gas in Saudi Arabia. Therefore, gasoline price reflects the outlook of both overall energy price and government energy policy as well. As per the discussion above, we hypothesise our STIRPART model as following:

$$CO_t = f(GDPC_t, OS_t, URB_t, (GP_t)) \quad (1)$$

where CO_t is a natural logarithm of CO₂ emissions metric tons per capita. $GDPC_t$ is the natural logarithm of real non-oil GDP per capita in Saudi Riyals. OS_t is the oil sector and is captured by the natural logarithm of the percentage of oil income in total GDP. URB_t is urbanisation and is captured by the natural logarithm of the percentage of the urban population in the total population. GP_t is captured by the natural logarithm of gasoline price and is a proxy for energy policy variable. It is sourced from Attala et al. (2018). All other variables are sourced from World Bank (2019) and the Saudi Arabian Monetary Agency (2019). t represents the annual period of 1970–2014. A maximum period is utilised in terms of the availability of data on our hypothesised model's variables. The share of oil income and share of domestic oil consumption are not available before 1970, and CO₂ emissions data are not available after 2014. The asymmetrical effects of macroeconomic variables may also be hypothesised, as Keynes (1936) argued that the increasing macroeconomic series shifted to the decreasing trend suddenly and sharply. Therefore, increasing the oil sector in the kingdom does not necessarily have the same effect on CO₂ emissions as of decreasing the oil sector. So, we are converting OS_t into two series of increasing and decreasing series

OSP_t and OSN_t following Shin et al. (2014):

$$OSP_t = \sum_{i=1}^t \Delta OS_i^+ = \sum_{i=1}^t \max(\Delta OS_i, 0) \quad (2)$$

$$OSP_t = \sum_{i=1}^t \Delta OS_i^- = \sum_{i=1}^t \min(\Delta OS_i, 0) \quad (3)$$

OSP_t and OSN_t in Eqs. 2 and 3 are the partial sums of positive and negative changes in the OS_t, respectively. Before proceeding to cointegration analysis, we test the unit root problem using the Augmented Dickey-Fuller (ADF) test proposed by Dickey and Fuller (1981), and the conclusion of the unit root problem is verified using Ng and Perron's (2001) methodology. Ng-Perron test is utilised for verification as it follows the de-trended series to test the unit root problem. Further, it proposes four modified statistics and is known for its efficiency, even in case of a small sample size, as in our case. After testing unit root in the series, we may move towards nonlinear auto-regressive distributive lag (ARDL) cointegration proposed by Shin et al. (2014). After replacing OSP_t and OSN_t with OS_t in Eq. 1, the nonlinear ARDL model can be described as follows:

$$\begin{aligned} \Delta CO_t = & \alpha_0 + \alpha_1 CO_{t-1} + \alpha_2 GDPC_{t-1} + \alpha_4 OSN_{t-1} + \alpha_5 URB_{t-1} \\ & + \alpha_6 GP_{t-1} + \sum_{j=1}^{m1} \beta_{1j} \Delta CO_{t-j} + \sum_{j=0}^{m2} \beta_{2j} \Delta GDPC_{t-j} + \sum_{j=0}^{m3} \beta_{3j} \Delta OSP_{t-j} \\ & + \sum_{j=0}^{m4} \beta_{4j} \Delta OSN_{t-j} + \sum_{j=0}^{m5} \beta_{5j} \Delta URB_{t-j} + \sum_{j=0}^{m6} \beta_{6j} \Delta GP_{t-j} + \psi_t \end{aligned} \quad (4)$$

where Δ is the first difference operator and shows the variables at their first differences. The subscripts $t-1$ with a variable shows the variable at 1 year lagged and $t-j$ shows $t-1, t-2, \dots, t-j$ where j is the optimum lag length ranging from $1-m_i$ for the dependent variable and ranging from $0-m_i$ for each independent variable. At first, the optimum lag length (m_i) can be estimated following Schwarz Information Criterion (SIC) as SIC is better to utilise in case of small sample size (Pesaran et al., 2001). Afterward, cointegration can be verified by a bound test on a null hypothesis of $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = \alpha_6 = 0$ using modified F -values provided by Kripfganz and Schneider (2018), which are efficient for the small size of sample size. A rejection of the null hypothesis can corroborate the long-run relationship/cointegration in Eq. 4. Then, we can calculate the long-run parameters by normalising procedure, and short-run impacts can be discussed through parameters of lagged-differenced terms in Eq. 4.

Results

Before the primary analysis, unit root analysis is conducted to ensure that the data do not have any issue of non-stationarity. ADF test is applied to assume C, C&T, and none in the test equation. Ng-Perron test is used to assume C and C&T in the test equation; results of the equation with C&T are presented in Table 2. In the ADF test, reported values are the t -values of ADF test statistics. In the Ng-Perron test, the reported values are Ng-Perron test statistics, i.e., MZa, MZt, MSB, and MPT. The results in Table 2 show that URB_t is stationary at level, assuming C in the ADF test equation. The rest of the results from ADF and Ng-Perron tests show that all variables are non-stationary at their level. Further, ADF test results show that all variables are stationary at their first difference at 1% level of significance. Moreover, Ng-Perron results show that all variables are stationary at their primary difference at 5% level. Overall, we may conclude a mixed order of integration, and we may move towards ARDL cointegration analysis, which provides efficient results even in case of a mixed order of integration due to its bound testing procedure (Pesaran et al., 2001).

The bound test is applied to the null hypothesis of no-cointegration after selecting the optimum lag lengths through SIC. The optimum lag lengths are selected as 1, 0, 0, 1, and 0 for the CO₂, GDPC_t, OSP_t, OSN_t, URB_t, and GP_t, respectively. The bound test result in Table 3 shows that the estimated F -value is higher than the critical upper values of Kripfganz and Schneider (2018) at 1% level of significance. So, the estimated nonlinear ARDL model is showing a high strength of long-run relation in Eq. 4. In the short-run results, the coefficient of ECT_{t-1} is negative and statistically significant. So, the short-run relationship is also corroborated in the estimated model with a speed of convergence of 56.97% in a year from short-run disequilibrium to the long-run equilibrium. Moreover, the p -values form estimated diagnostic tests are at least higher than 0.1 and show that the estimated model is out of any econometric problems.

Discussions

In the long-run results, a positive and statistically significant coefficient of OSP_t shows a positive and elastic impact of increasing oil income share in GDP on the CO₂ emissions per capita in Saudi Arabia. This country-specific result corroborates the findings of Roberts et al. (2019); the future global oil production is expected to increase GtCO₂ emissions and is also in line with a positive relationship between the oil rents and CO₂ emissions found by Bekun et al. (2019). Our estimated elastic

Table 2 Unit root tests' results.

Variable	ADF test			Ng-Perron test (C&T)			
	None	C	C&T	MZa	MZt	MSB	MPT
CO _t	0.8364(0)	-2.5703(2)	-2.5374(3)	-9.6215(0)	-2.1922	0.2279	9.4757
GDPC _t	0.6936(1)	-1.7846(0)	-1.9339(0)	-6.1388(0)	-1.7449	0.2849	14.8417
OSP _t	1.5147(0)	-1.3507(0)	-0.9973(0)	-9.6005(0)	-2.0945	0.2182	9.8954
OSN _t	1.7246(1)	-0.7618(0)	-1.8394(1)	-6.9562(1)	-1.8555	0.2668	13.1108
GP _t	-1.5908(0)	-1.1191(0)	-1.3937(0)	-11.2104(1)	-2.2830	0.2037	8.5531
URB _t	-0.0084(1)	-2.6908*(1)	-2.7090(1)	-0.8798(1)	-0.4539	0.5159	56.0412
Δ CO _t	-7.1063*** (0)	-7.1396*** (0)	-7.0398*** (0)	-21.0862*** (0)	-3.2274**	0.1531**	4.4403**
Δ GDPC _t	-3.7807*** (1)	-4.6987*** (0)	-5.2276*** (1)	-18.6478*** (0)	-3.0532**	0.1637**	4.8888**
Δ OSP _t	-3.1083*** (1)	-6.7839*** (0)	-6.8783*** (0)	-21.3499*** (0)	-3.2669**	0.1530**	4.2706**
Δ OSN _t	-3.4920*** (0)	-4.8016*** (0)	-4.7876*** (0)	-19.3584*** (0)	-3.1068**	0.1605**	4.7339**
Δ GP _t	-4.9589*** (0)	-5.0261*** (0)	-5.0029*** (0)	-20.2915*** (0)	-3.1850**	0.1570**	4.4924**
Δ URB _t	-5.6217*** (0)	-3.8373*** (0)	-4.4888*** (1)	-20.9703*** (0)	-3.2366**	0.1543**	4.3542**

C is for the intercept, and T is for time trend. *, ** and *** are showing stationarity at 10%, 5% and 1% level of significance, respectively. () contains optimum lag length selected through SIC.

Table 3 Estimated results from the nonlinear ARDL model.

Variable	Coefficient	Standard error	t-statistics	Probability
Long-run				
$GDP C_t$	0.3449	0.0699	4.9340	0.0000
OSP_t	2.2528	0.5386	4.1827	0.0002
$>OSN_t$	0.4673	0.2189	2.1354	0.0396
Wald test	Chi-Square = 8.5910	0.0058		
URB_t	1.8766	0.9255	2.0275	0.0501
GP_t	-0.1127	0.0526	-2.1423	0.0390
Intercept	-10.0956	3.8715	-2.6076	0.0132
Short-run				
$\Delta GDP C_t$	0.1971	0.0489	4.0298	0.0003
ΔOSP_t	1.2834	0.3091	4.1514	0.0002
ΔOSN_t	0.2662	0.1354	1.9669	0.0569
Wald test	Chi-square = 57.8734	0.0000		
ΔURB_t	0.3549	0.0915	3.8777	0.0004
ΔGP_t	-0.0642	0.0303	-2.1214	0.0408
ECT_{t-1}	-0.5697	0.1031	-5.5265	0.0000
Diagnostic tests				
Bound test	F-value = 5.2299			
	Critical bound F-values			
	At 1% 3.0379-4.1121			
	At 5% 2.3851-3.3551			
	At 10% 2.0766-2.9892			
F-Hetro	1.5332			0.1875
F-Serial	0.7157			0.4960
F-RESET	0.2318			0.6332
χ^2 -Normality	1.7680			0.4131

impact explains that the CO₂ emissions are changed more than proportionate with a proportion change in the OSP_t. For example, a 1% increase in OSP_t is responsible for a 2.2528% increase in the CO₂. It indicates the fact that when the country can generate more income from the oil sector, CO₂ emissions in the country increase at a higher rate.

On the other hand, if the government could stop increasing the oil sector income by 1%, then she can stop 2.2528% of CO₂ emissions. It puts a question on the business activities of the oil sector since if the country is eventually facing some higher CO₂ emissions, the benefit of income from the oil sector might subsequently be set off because higher CO₂ emissions have their social cost on the society that is not being accounted for. The coefficient of OSN_t is positive and statistically significant. Hence, decreasing oil income share in GDP is helping to reduce the CO₂ emissions per capita, and 1% decrease in OSN_t decreases 0.4673% of CO₂. The effects of OSP_t is found about 5 times higher than that of OSN_t. Therefore, the damaging environmental effect of the growing oil sector is found more than that of the environment, improving the effect of decreasing the oil sector. This asymmetrical effect of the oil share of income is tested by the Wald test and is also corroborated by rejecting the null hypothesis of symmetry at 1% level of significance.

One factor worth mentioning here is the carbon capture and renewable energy credits that can potentially help the Saudi economy in coping with the higher emissions as a result of oil sector income. It is so because, with every unclean product in the oil or any other sector, there is a potential that the disadvantage to the environment can be offset through renewable certificates that the owners of renewable energy can issue. In the Western world, it is a popular method of countries to increase the revenue for renewable generators and also put a cap on the amount of non-renewable energy a certain producer can produce through these certificates. Although non-renewable energy that harms the environment still gets generated if a producer buys those

certificates, it is a good way to put a cost on those activities to discourage the production and consumption of non-renewable energy.

Non-oil GDP per capita shows a positive but inelastic effect on the CO₂ emissions per capita with a statistically significant coefficient of GDP C_t. This result is in line with the monotonic positive effect of GDP per capita on the CO₂ emissions in Saudi Arabia reported by Raggad (2018), Farhani et al. (2014), and Samargandi (2017). Our estimated elasticity coefficient shows that 1% increase in GDP per capita is responsible for 0.3449% increase in the CO₂ emissions per capita. This result corroborates the affluence effect as increasing economic growth, average consumption, and economic activities may pollute the environment due to higher consumption of energy. These results support the theoretical discussion that the higher economic activities lead to business activities that are more inclined towards degrading the environment. In these instances, it is up to the government and the business sector to set their priorities straight and pick aside. The inelastic effect shows a lack of flexibility in this effect, which indicates that there is a higher need for strict policy implications to come up with environmental targets. These solutions can be introduced in the form of higher taxes for economic activities, leading to higher emissions, putting a cap on the emission rate by the producer or by region, promoting renewable energy credit, and giving tax relief to renewable energy producers or many more.

The coefficient of GP_t is negative, statistically significant, and inelastic. It shows that 1% decrease in GP_t would increase 0.1127% of the CO₂ emissions per capita. The statistically significant effect of gasoline price on the CO₂ emissions is in line with the finding of Attala et al. (2018), who found a substantial relationship between gasoline price and gasoline demand in Saudi Arabia. They argued that the gasoline price is lower than the international market due to government subsidies, and increasing gasoline prices could manage the energy efficiency and environmental consequences. Gasoline price is mostly fluctuated by

government energy subsidies or taxes. The decreasing trend of GP_t shows increasing government subsidies or decreasing taxes. The result shows that a relaxed energy policy in terms of decreasing gasoline price is harmful for the environment. On the other hand, tighter energy policy may have positive environmental effects by reducing CO_2 emissions. Though the effect of gasoline price on the CO_2 emissions is inelastic, but still, its effect is statistically significant. This result may be utilised by the government while targeting the reduction in pollution emissions through energy price policy.

Moreover, the coefficient of URB_t is positive, elastic, and statistically significant. A positive effect of urbanisation on the CO_2 emissions was also reported by Omri et al. (2015) in the case of Saudi Arabia, but Raggad (2018) found the negative effect of urbanisation on the CO_2 emissions in Saudi Arabia. However, both studies have attempted specification biasness by including energy consumption in the CO_2 emissions' model, which is responsible for changing magnitude and/or sign of other determinants of CO_2 emissions (Jaforullah and King, 2017). Our estimated elasticity coefficient of urbanisation explains that 1% increase in URB_t would increase 1.8766% of the CO_2 emissions per capita. The proportion of the urban population in the total population is continuously increasing throughout the sample period. It means that continuous increasing urbanisation has continued negative environmental consequences. The positive link between urbanisation and CO_2 emissions is corroborated by the theoretical discussions. In any urban setting, activities of urbanisation lead to more construction and developmental projects since the trend is to urbanise the societies and people are moving to these more modern parts of the country. With all of that development comes with the environment burden because no construction can be done without using natural resources and fuel, which degrades the environment. Thinking about it from a long-term perspective, building more houses might not be an ideal situation because all of that piles up and eventually affects the same people living in the urban parts of the country and reduces their overall welfare. The contribution of urbanisation in the CO_2 emissions is found more than proportionate. Therefore, the government should tax all the activities of the urban population, which are pollution oriented, and its revenue should be invested in cleaner technologies to be provided to urban areas.

In the short-run, the non-oil GDP per capita has a positive, inelastic, and statistically significant effect on the CO_2 emissions per capita. It means that the affluence effect is also vital in the short-run, and 1% increase in GDP per capita would increase 0.1971% of CO_2 emissions per capita. OSP_t has positive, significant, and elastic effects on the CO_2 emissions per capita with a coefficient of 1.2834. It means that increasing 1% oil share income is responsible for increasing 1.2834% of CO_2 emissions per capita. Moreover, decreasing the oil share of income OSN_t has a positive but inelastic effect on the CO_2 emissions in the short-run. Therefore, reducing the oil sector share of income is also helping in protecting the environment even in the short-run.

The different magnitudes of increasing and decreasing oil sector income share are corroborated the asymmetrical effects of oil sector income on the CO_2 emissions. This result is also verified by the Wald test by rejecting the null hypothesis of symmetry at 1% level of significance in the short-run. Further, gasoline price has a negative and inelastic effect on CO_2 emissions per capita in the short-run. 1% decreasing gasoline price is responsible for increasing 0.0642% of CO_2 emissions per capita. At last, the positive and inelastic effect of urbanisation is found with a statistically significant coefficient of 0.3549, and 1% increase in URB_t is responsible for increasing 0.3549% of CO_2 emissions per capita in the short-run.

Conclusions

The oil sector could have a negative environmental effect in an oil-abundant economy in Saudi Arabia. This present research explores this issue by employing a nonlinear ARDL cointegration technique and using an annual data series of 1970–2014 and STIRPART model for Saudi Arabia. A proxy of the oil sector, i.e., the percentage of oil income in GDP, is used to estimate its environmental effect through CO_2 emissions per capita. Further, the asymmetrical impact of the oil sector has been investigated to complete the information on potential asymmetry in the model, which is diagnosed from the co-movements of oil income share and CO_2 emissions per capita. Moreover, real non-oil GDP per capita is regressed in the CO_2 emissions model to test the affluence effect, and gasoline price is also regressed to capture the energy policy effect on the CO_2 emissions.

Our estimates show that we have found long-run and short-run relationships in the hypothesised model. Further, GDP per capita has a positive and inelastic effect on the CO_2 emissions per capita. The inelastic effect explains that CO_2 emissions per capita are increasing less than proportionate with a proportionate increase in income, but still increasing income is responsible for environmental degradation by releasing more CO_2 emissions. The effect of increasing oil sector income share is found positive and elastic in both the long- and short-run. The elastic effect explains that CO_2 emissions per capita are growing more than proportionate, with a proportional increase in increasing oil sector income share. Further, the elasticity of the effect of rising oil sector income on the CO_2 emissions per capita is found more significant compare to other regressed determinants. The impact of decreasing oil sector income share is also found positive but inelastic in the long and short-run. Hence, the asymmetry in the relationship of oil sector income share and CO_2 emissions is found, and this asymmetry is corroborated with the Wald test both in the long and short-run. The urbanisation is seen to positively impact the CO_2 emissions with elastic effects in the long-term and inelastic effect in the short-run. Lastly, the negative effect of gasoline price on the CO_2 emissions per capita is found inelastic both in the long and short-run. Therefore, a relaxed energy policy is dangerous for the environment, and the tight energy policy is helpful in reducing CO_2 emissions.

The results of the study advocate strict environmental policy implications for Saudi Arabia while targeting economic growth goals. The country must look to create a balance between its ecological and growth strategies so that one does not get ignored due to the other. Moreover, Saudi Arabia should reduce the oil dependence as increasing oil sector income share is found the most significant contributor in the CO_2 emissions per capita. Although Saudi Arabia has made some contributions to be a part of the international climate change movements and the Vision 2030 is also carrying the green environment policy by reducing pollution emissions. However, it may take a long time, especially if the country is aiming to become smarter in terms of devising a sustainable growth strategy. As mentioned in a variety of literature, oil-exporting countries like Saudi Arabia should be more sophisticated in terms of their environmental policies and make them conservative to some extent so that there is not a perfect trade-off between economic growth and the environment and both can be achieved to some extent. Saudi Arabia can incorporate tax on gasoline prices so that CO_2 emission can keep under control, and government revenue may also improve, which can be utilised for renewable projects. Additionally, more subsidies can be provided to companies investing in renewable energy as a part of the environment-friendly regulations. Keeping a balance between renewable and non-renewable resources is the only solution to keep a cleaner environment of oil-rich economy of Saudi Arabia.

Data availability

The data set analysed during the current study is available in the Dataverse repository: <https://doi.org/10.7910/DVN/Z81EID>.

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Competing interests

The authors declare no competing interests.

Additional information

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